

# Can spending to upgrade electricity networks to support electric vehicles (EVs) roll-outs unlock value in the wider economy?

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## ABSTRACT

We investigate the question of whether spending to enable ambitious EV roll-out programmes can in fact generate net gains across the wider economy. We use a multi-sector computable general equilibrium (CGE) model for the UK economy and focus on the need to upgrade electricity networks to support an initial EV penetration scenario for the period to 2030. We find that large scale spending and cost recovery for network upgrades is likely to result in net negative impacts on key macroeconomic indicators, including real income available for spending across all UK households. This is due to a combination of time-limited network upgrade activity in the presence of capacity constraints combined with the need for costs to be passed on to electricity consumers through higher bills. But the lowest income households – the group of greatest concern to policy-makers – suffer the smallest losses. Moreover, the EV uptake delivers sufficient gains that deliver net positive impacts on all household incomes, with sustained expansion in GDP and employment across the economy. The key driver is a greater reliance on UK supply chains with the shift away from more import-intensive petrol and diesel fuelled vehicles towards electric ones.

## 1. Introduction

The UK and Scottish Governments have set ambitious targets for the roll-out of electric vehicles (EVs) by 2040 and 2032 (DEFRA 2017; Scottish Government 2017).<sup>1</sup> These targets have been driven by the global recognition that EVs are a viable alternative to traditional fossil fuels vehicles and a key low carbon solution and technology for supporting the transition to the decarbonisation of transportation (European Commission, 2014; IEA, 2017). Moreover, with the Paris Declaration on electro-mobility and climate change aiming to increase electric-mobility to levels compatible with a less than 2°C pathways (United Nations, 2015), advancing electrification of transport has become a stated priority for most countries. Electric Vehicles Initiative (EVI) member countries have taken renowned lead in this respect. For instance, Norway set national targets of new vehicles to emit on average 85 g CO<sub>2</sub>/km by 2020 (Norway Government, 2014). Germany plans to roll-out at least 1 million electric and plug-in hybrid vehicles by 2020 as

declared in the national electro mobility development plan (German Federal Government, 2009). The UK Government has set a target of at least 50% of new vehicles to be ultra-low emission by 2030 in the recently launched 'Road to Zero Strategy' (HM Government, 2018; Office for Low Emission Vehicles, 2018).

But, if the EV roll-out is to play its intended role in supporting national priority of reduction in greenhouse gas (GHG) emissions, it must gain support from a broad policy stakeholder community. In the paper we argue that a crucial element of this is demonstrating that the EV roll-out can contribute to unlocking, sustaining and increasing value in different parts of the economy. An obvious focus is locating the manufacture of vehicles and batteries 'at home'. Our proposition is that a more straightforward source of wider economy value may result from EVs being fuelled by the domestic electricity industry, which may support more extensive domestic supply chain activity than petrol/diesel fuelling. We have previously argued this in a simpler economy-wide input-output (IO) multiplier framework (Turner et al., 2018). Here we

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<sup>1</sup> In May 2019 the Committee on Climate Change - an independent, statutory body established under the Climate Change Act 2008 to advise the UK national and devolved governments – recommended that the UK target to end new sales of petrol and diesel vehicles by 2040 be brought forward so that CO<sub>2</sub> emissions may be further reduced by 2050. The Committee on Climate Change (2019) advice is set in the context of more ambitious 'net zero' targets in line with the lower, 1.5 °C aims set out in the 2015 Paris Agreement.

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extend using multi-sector economy-wide computable general equilibrium (CGE) analysis to consider a fuller range of spending activities and market responses, which drive a range of distributional effects through income and price effects.

Like any transformative low carbon solution and technology, EVs presents a variety of challenges for the vehicles industry, fuel station operators, electricity network and the government. In particular, the EVs roll-out will have profound impact on the electricity system that will require upgrade to the electricity network itself, which will carry significant costs that are ultimately paid by consumers. Here we consider how consumers may be impacted both through energy bills and the costs of other goods and services (where electricity prices impact production costs). But we also investigate the extent to which benefits triggered by the shift to domestically fuelled (and increasingly more efficient) EVs may act to offset losses incurred.

The remainder of the paper is organised as follows. Section 2 provides a synopsis of the existing and emerging discourse and debate around EV roll-out. Section 3 sets out the core principles adopted in investigating the question of who pays and who benefits from the upgrade of the UK electricity network infrastructure and associated EV roll-out. Section 4 details the CGE model specification and characteristics. Section 5 presents and explains our results. Conclusions and policy implications are provided in Section 6.

## 2. Background to questions around EVs in the literature

Several studies have applied various methods to estimate the implications and impacts of the roll-out of EVs. Some have largely focussed on the factors promoting and driving the shift to EVs, charging infrastructure requirements, and the demand and/or consumer choice and behaviour of switching to alternative fuel vehicles (Egbue and Long, 2012; Jacobson and Delucchi, 2011; Miesel and Merfeld, 2018; Noel et al., 2017; Noel et al., 2019). Fernandez et al. (2011) focus on the impacts of different levels of plug-in EVs penetration on distribution network investment, evaluation of network reinforcement and incremental energy losses. Lopes et al. (2011) evaluates the integration of EVs in the electric system and the grid control architecture and mechanism required.

Other studies assess the potential economic cost and benefits of the EVs roll-out and the potential market penetration (Carlsson and Johansson-Stenman, 2003; Noel and McCormack, 2014; Schmelzer and Miess, 2015; Villar et al., 2013). Another strand of the literature focus on the environment impact and technical progress associated with EVs (Cames and Helmers, 2013; Choma and Uyaya, 2017; Neves et al., 2018).

Some authors highlight the need for active government support to incentivise and accelerate large-scale transition to EVs. These studies focus on using a combination of new and possibly innovative policy interventions and instruments, generally taxation and subsidies (See for examples Adderly et al., 2018; Lopez-Behar et al., 2019; Wang et al., 2018). On the other hand, there may be a gap in the literature in this regard, given the attention that policymakers and regulators have been giving to both developing and implementing mechanisms that protect consumers against higher electricity bills (which in turn impacts income and spending) and different charging regimes and infrastructure (Ofgem, 2018).

In terms of methodological approaches, most existing EV studies employ bottom-up models (e.g. optimization, statistical methods and simulation models) to consider the potential economic and technological implications of EV uptake (Gnann and Plotz, 2015). These type of modelling frameworks are frequently used to analyse the impacts of integrating EVs with the electricity system/network, grid control design, type of charging infrastructure and vehicle efficiency to support EVs uptake and deployment (see for example de Rubens, 2019; Link et al., 2012; Richardson, 2013; Tran et al., 2013). This is important as bottom-up models and methods have a key role to play in developing

wider evidence base to enable a detailed understanding of the potential impacts of what are expected to be large-scale shifts towards electric vehicles in many countries. On the other hand, bottom-up approaches are more limited in terms of insights on a fuller range of indirect and economy-wide benefits that are of concern to the wider policy stakeholder community (Turner et al., 2018).

There are a number of studies that employ top-down models (e.g. input output and computable general equilibrium (CGE) methods) in investigating issues around EVs roll-out (see, for example, Figus et al., 2018; Li et al., 2017; Hirte and Tscharktschiew, 2013; Turner et al., 2018). A common and generic consensus across most studies is that EVs roll-out will have both positive and negative impacts on the wider economy and vehicle users (Lemoine et al., 2008; Wu et al., 2019; Villar et al., 2013). Some of the positives impacts include; reducing vehicle operating cost, support to national and global CO2 emission reduction objectives; improved local air quality and the provision of a stable and sustainable electricity system (Noel and McCormack, 2014). On the other hand, the market barriers and disadvantages include, high prices; short drive ranges; long recharging times and an insufficient recharging infrastructure (Berkeley et al., 2018; O'Neil et al., 2019; Steinhilber et al., 2013; Vassileva and Campillo, 2017).

### 2.1. Addressing the question of 'who pays', and 'who gains'

In this paper we focus attention on the distribution of costs and benefits that may arise from the need for large scale spending to upgrade the capacity and resilience of the electricity network to enable the roll-out of EVs. In doing so we identify four underlying principles.

First, certainly in a UK case, funding the necessary network upgrade spending by the electricity industry requires cost recovery through electricity bills. The industry standard is that the cost can be recovered over a relatively long timeframe (equating to the estimated lifetime of new assets). Although they may ultimately be recovered more directly from EV users as uptake increases, we assume that recovery of the total investment costs is spread evenly over the lifetime of the assets created by the investment and reclaimed through bills.

Second, commercial electricity customers are likely to pass on their increased energy costs through their own output prices. Ultimately, this will ripple through to domestic consumers in prices of other goods and services. Where firms export their output, the impact on UK households may be less direct, emerging through the employment and income effects of any loss in competitiveness.

Third, where capacity constraints exist across the economy, the process of upgrading the UK electricity network infrastructure through large scale investment could trigger further price increases and negative wider economy impacts as different sectors involved draw in additional (but scarce) labour and capital resources.

Fourth, the uptake of EVs enabled by the network upgrade could of course trigger a stream of benefits. Based on the findings of our previous work (Turner et al., 2018), in the UK case we hypothesise that a key source of benefits is likely to be economic expansion triggered by a shift in demand away from petrol/diesel (which has an import-intensive supply chain) towards electricity in fuelling vehicles, where the UK electricity industry has strong domestic supply chain linkages. Moreover, where EVs are more efficient, in terms of the cost per mile driven, this may further trigger a demand-driven stimulus as real incomes rise and purchasing power is freed up for spending on other goods and services.

These basic principles are subject to practical complexity, particularly in terms of the timeframe over which the required network

investment is carried out relative to the timing of the expected realisation of benefits through the EVs uptake.

First, if we assume that producers are forward looking,<sup>2</sup> in that they will recognise and anticipate when any large-scale investment is time limited to meet a particular requirement, this will influence both sectoral and market responses to that investment. Any major demand shock to the economy puts pressure on resources and prices. But if this is concentrated in a short timeframe (i.e. the investment boost is large but time-limited), the impact can be more disruptive as resources are first drawn away then released again, with the latter potentially triggering negative net impacts at sectoral and economy-wide levels. Where producers anticipate this, they will be less willing to reallocate resources in the first place, which will dampen the expansionary process while also pushing up prices.

In the context of the spending required to upgrade the electricity network to support the projected EV roll-out to 2030 for the UK, the potential for this type of ‘crowding out’ raises questions as to how the investment required should be spread. On the one hand, industry regulators may be cautious about creating new capacity too far ahead of the projected requirement in case that does not materialise, and/or it impacts the efficiency with which existing capacity is used. On the other hand, particularly with capacity constraints relaxed over time, the disruptive impacts of the network investment on the wider economy are likely to be lessened if the spending and upgrade activity are spread over a longer timeframe in the lead up to 2030.<sup>3</sup>

This leads us to a second point. By 2030 the expected UK EV penetration is only anticipated to be 20% (Calvillo and Turner, 2019; National Grid, 2018). It may then be argued that effective planning for a mass roll-out of EVs actually requires a continuous investment to meet desired penetration levels. Our sensitivity analysis (Section 5.3) considers how the anticipation of further investment may impact supply-side responses to the initial phases of investment simulated here. However, there are questions as to how an ongoing programme of investment to support network upgrades would be planned for in practice. In the UK, network investment decisions are made on the basis of 5-year (previously 8-year) blocks which are referred to as ‘price control’ periods (Pearson and Watson, 2012; SPEN, 2018) – which are different for transmission and distribution parts of the industry – and set in the context of initial delivery of outcomes/benefits within the same block of time. A further complication is that supporting the EV uptake is not the only demand on the UK electricity network: investment may spread across different price control periods in order to consider wide low carbon electrification programmes and actions/options.

### 3. Method

We apply the UK-ENVI CGE model developed through various previous studies (e.g. Allan et al., 2007; Turner, 2009; Lecca et al., 2014; Figus et al., 2017, 2018). Specifically, we develop the variant applied by Figus et al. (2017) – with disaggregation of households by income quintiles – with further refinements made by Figus et al. (2018) to focus on the composition and efficiency of private transport. The model is calibrated on a 2010 social accounting matrix, SAM, for the UK (the most recent year for which appropriate data are available). In this section we identify key elements of the UK-ENVI framework that govern the outcomes of simulation scenarios designed to consider the issues set out

in Section 3.

#### 3.1. Simulation requirements

Two stages need to be simulated. The first is the impacts of a spending and cost recovery programme to enable electricity network upgrades. We focus on a scenario – informed by Calvillo and Turner (2019) energy system simulations, in turn based on a National Grid (2018) scenario – that includes some extent of centralised and smart charging. This requires a total spend of £2.7 billion to support 20% EV penetration by 2030. We assume that this may be spread over a 12 year period (2021–2032) or condensed in the 3 years immediately before 2030 (2027–2029).

In consultation with one of the UK network operators (SP Energy Networks) we have determined that only one-third of the total spend is likely to be made in the UK. All other equipment required are imported from the rest of the world (ROW). Thus, while UK (commercial, public sector and household) consumers must repay the total amount spent, over 45 years for the life span of the asset, only £900 million of total spend is made in the UK. This is Scenario 1.<sup>4</sup>

Scenario 2 involves adding and considering the impacts of the projected 20% EV roll-out. This involves adopting UK-ENVI specifications introduced by Figus et al. (2018), with adjustment to permit the adoption of EVs. We develop this further using informed exogenous data (outputs of Calvillo and Turner, 2019 energy system scenario analyses) on a 20% EV penetration by 2030 uptake and gradual boost in the efficiency of EVs in using electricity to deliver private transport services (to 20% by 2030).

#### 3.2. Key elements of the model specification

Figus et al. (2017, 2018) discuss in detail the fuller model specification of the UK-ENVI. Here we adopt the same broad configuration, in terms of national fixed labour supply, forward looking producers, myopic consumers and export demand. This section focuses on key elements of specification required to simulate the scenarios set out above.

##### 3.2.1. Production structure

Fig. 1 illustrates the production structure in each of the 30 industries in the UK-ENVI framework. It reflects the classical KLEM nested constant elasticity of substitution (CES) production function, where the input decisions in each sector involve CES relationships between inputs of intermediate goods, labour and capital. In each sector, intermediate inputs and value-added produce total output. Intermediate inputs are a combination of energy and non-energy. Capital and labour form value-added. Energy is divided into electricity and non-electricity.

To capture the impacts of EV roll-outs, a new and distinct industry; ‘EVs Manufacturing’ is created within the industrial structure. This industry produces a designated output (i.e. EVs), therefore the total number of production sectors is expanded to 31 industries (see Table A1 in Appendix A). However, the EVs Manufacturing industry has the same production structure as the original 30 industries, thus, the same labour closure and electricity price effects apply. Note that in identifying a ‘EVs Manufacturing’ industry we are in fact disaggregating the existing UK ‘Motor Vehicles Manufacturing’ industry identified in the national accounts. We do so by assuming that in the base year the production of EV constitutes 2% of total production of vehicles, while conventional petrol

<sup>2</sup> The impact of the reaction and response of forward-looking producers to investment decisions has been widely discussed in literature. The assumption of forward-looking consumers is also a key question of specification in the type CGE modelling approach adopted in this paper (see Lecca et al., 2013).

<sup>3</sup> This type of issue may form part of the concern expressed by the Committee on Climate Change (2019, p.182), where it is noted that “... networks will need to be upgraded in a timely manner and future-proofed to limit costs and enable rapid uptake of electric vehicles and heat pumps”.

<sup>4</sup> In Scenario 1, we consider the impacts of the network upgrade on key macroeconomic variables including the impacts across different household quintiles. However, for Scenario 2, in the absence of required data on which household groups will purchase EVs, we switch off the household disaggregation element and consider a single representative household. In future research, we will prioritise capturing the impacts of increased EVs penetration on different household income groups.

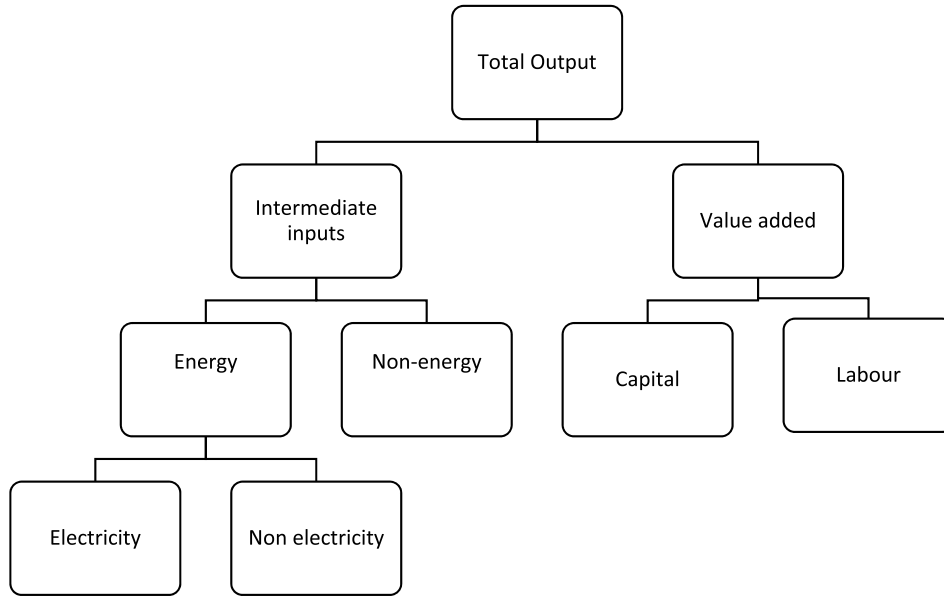


Fig. 1. Production structure.

and diesel vehicles are 98%. Crucially, we break out these vehicles manufacturing sectors to enable substitution between non-electric and new EV vehicles (as it rolls out) in the household consumption choice for private transportation. We return to this in more detail in Section 4.2.3.

In our core scenario, we assume that all producers are forward looking and have perfect foresight. Capital stocks accumulate over time through investments. The investment decision follows Hayashi (1982), where maximization of the value of firms,  $V_t$ , is subject to a capital accumulation function  $\dot{K}_t$ , so that

$$\text{Max} \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} [\pi_t - I_t(1+g(\omega_t))] \quad \text{subject to} \quad \dot{K}_t = I_t - \delta K_t \quad (1)$$

where  $\pi_t$  denotes firms' profits,  $I_t$  is private investment,  $g(\omega_t)$  is the adjustment cost function, with  $x_t = I_t/K_t$  and  $\delta$  is the depreciation rate. The solution of the problem gives the law of motion of the shadow price of capital  $\lambda_t$  and the adjusted Tobin's  $q$  time path of investment (Hayashi, 1982). In Section 5.3 we consider an alternative scenario where producers are myopic, and do not anticipate that the spending will end. This is motivated by the likelihood that continued spending on UK electricity network upgrades will be required to support a wider programme of electrification, so that any reaction to an anticipated end to the programme may introduce negative effects that might not occur in practice. This involves replacing (1) with a simple capital stock adjustment procedure, according to which investment in each time period equals depreciation plus some fraction of the gap between the desired and actual capital stock (see Lecca et al., 2013).

### 3.2.2. Labour market

We assume that the labour market is characterised by a fixed national labour supply (albeit with a pool of unemployed labour as reported in the base year data given by the SAM) and that the nominal wage is fixed. The motivation for this assumption is that recent labour market conditions suggest that UK workers have not generally been in a position to effectively negotiate/bargain their wages in response to changing economic conditions. We model wage setting with fixed nominal wage, which is determined as follows:

$$w_t = w_{t=0} \quad (2)$$

where the nominal wage for the time period,  $w_t$  is constant and unchanging. In Section 5.3 we consider an alternative wage setting

assumption, where wages are determined within the region in an imperfect competition setting, according to the following wage curve:

$$\ln \left[ \frac{w_t^b}{cpi_t} \right] = \phi - \varepsilon \ln(u_t)$$

where

$$w_t^b = \frac{w_t}{1 + \tau_t} \quad (3)$$

where the bargaining power of workers and hence the real consumption wage is negatively related to the rate of unemployment (Blanchflower and Oswald, 1994). In (3),  $\frac{w_t^b}{cpi_t}$  is the real after tax consumption wage,  $\phi$  is a parameter calibrated to the steady state,  $\varepsilon$  is the elasticity of the wage rate with respect to the rate of unemployment,  $u$ , and takes the value of 0.113 (Layard et al., 1991), and  $\tau_t$  is the income tax rate which is fixed in the default setting.

### 3.2.3. Consumption

Fig. 2 represents the consumption structure in the model. Each household allocates consumption between household electricity, transport and non-energy. In each time period consumption decision of each representative household is expressed in general form as

$$C_{h,t} = Y_{h,t} - S_{h,t} - HTAX_{h,t} - CTAX_{h,t} \quad (4)$$

In Equation (4),<sup>5</sup>  $C$  denotes total consumption,  $Y$  income,  $S$  savings,  $HTAX$  income tax and direct taxes of consumption,  $CTAX$ .  $t$  denotes time, which is considered to be one year (given that underlying data are annual). We assume that consumers are myopic<sup>6</sup> and their intra-temporal utility function is a nested CES, where at each node consumption decisions depend on relative prices and on the elasticity of substitution as represented in Fig. 2.

The main innovation here is within the transport level nest in Fig. 2, specifically how EVs enter the model. To simulate the required EV roll-out, we assume that the elasticity of substitution between electric (ET)

<sup>5</sup> Note that when the household disaggregation element is switched off the  $h$  index is removed.

<sup>6</sup> This means consumer base their spending decisions on current income available rather than on future discounted utility of consumption (see Lecca et al., 2013).



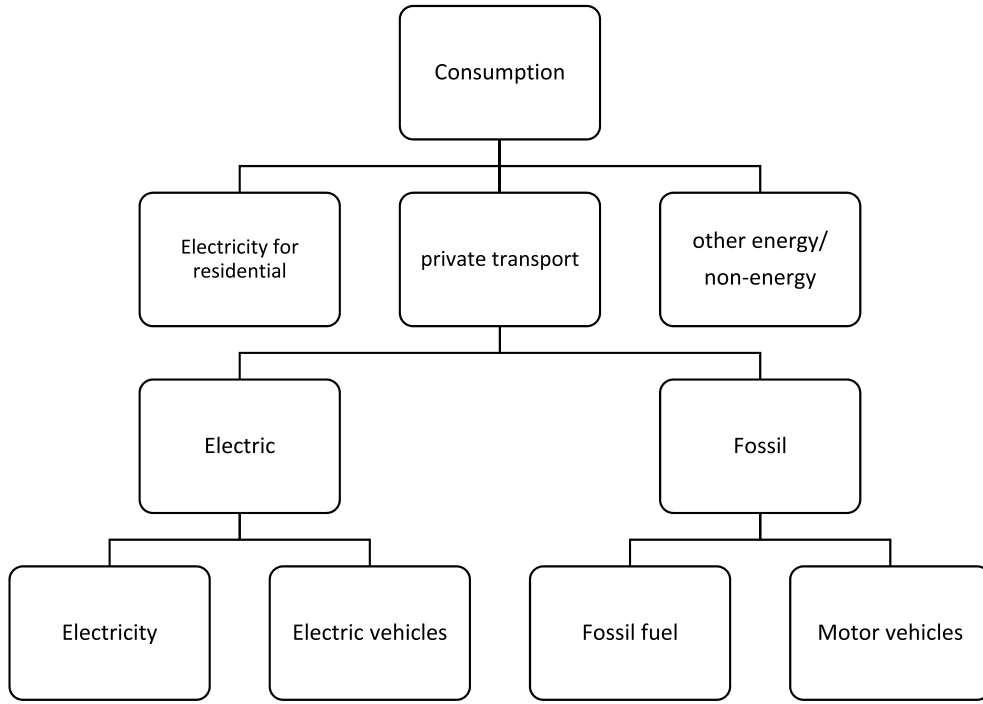


Fig. 2. Structure of consumption.

and fossil transport (NET) is zero in private transportation and Leontief demand functions are derived as follows:

$$NET_t = \beta_t^{NET} T_t$$

$$ET_t = \alpha_t^{ET} T_t \quad (5)$$

where  $T$  is total private transport,  $\alpha_t^{ET}$  is the share of electric transport consumed by households, and  $\beta_t^{NET}$  is the share of non-electric transport. So that  $\alpha_t^{ET} + \beta_t^{NET} = 1$ . It is important to split total private transportation in this way to enable the choice of substitution in household decision for private transportation. Initially,  $\alpha_t^{ET}$  is calibrated to reflect the current share of EVs in total private transportation, which is assumed to be approximately 2%. However, over time,  $\alpha_t^{ET}$  is determined exogenously to simulate the increased penetration of EVs, simultaneously driving down the share of non-electric (conventional petrol/diesel) vehicles,  $\beta_t^{NET}$ . A crucial point to note here is that due to the Leontief specification within the transportation nest the shares of conventional motor vehicles and EVs remain unaffected by fluctuation in the price of fuels, be it refined petroleum products or electricity.

### 3.2.3. Impact of network improvement on prices

For the simulations under scenario 1, the UK component of the spending to upgrade the electricity network to support the EV roll-out is introduced through an increase in exogenous final demand for construction sector output. However, the full cost of this spending (including the larger imported share) is passed on to the consumers/electricity users via higher electricity bills until the full investment cost is repaid. The repayment period levels to the lifetime of the new assets. We capture the impact on the electricity price and electricity demand in equation (6):

$$ELE_{h,t} = \delta_h^{ele} \left( \frac{PET_t}{P_{ele,t}} \right)^{\rho^{et}} \cdot ET_{h,t} \quad (6)$$

$$ELE_{h,t} = \delta_h^{oc} \left( \frac{CPI}{P_{ele,t}} \right)^{\rho^c} \cdot C_t \quad (7)$$

Equations (6) and (7) are demand functions for electricity used by households for transport and for residential purposes respectively. In both expressions ELE is household demand for electricity. In (6) ET is electric transport, PET is the price of electric transport, and  $P_{ele}$  is the price of electricity,  $\delta_h^{ele}$  is a share parameter and  $\rho^{et}$  is the elasticity of substitution between electric vehicles and electricity. In (7)  $C$  is total household consumption, CPI is the consumer price index, and  $\rho^c$  is the elasticity of substitution between the consumption of energy for residential purposes and the consumption of other goods and service.

$$VVe_{j,t} = \left( A^{EF} \left( \delta_j^{vele} \right)^{\frac{1}{1-\rho_j^E}} \cdot \frac{PE_t}{P_{ele,t}} \right)^{\frac{1}{1-\rho_j^E}} \cdot VVEN_{j,t} \quad (8)$$

Similarly, in (8) VVe is electricity demanded by each industry in the economy  $j$ ,  $A^E$  is a productivity parameter,  $\rho_j^E$  is the elasticity of substitution between electricity and non-electricity demand in production, PE is the price of the composite good energy, and VVEN is industrial demand of total energy.

In the model the price of electricity is endogenous and is a function of all the other prices in the model. Agents pay the same price  $P_{ele}$  as can be seen in equations (9) and (10). In order to increase the revenues from the sales of electricity and pay for the network upgrades, electricity supplying firms increase the price  $P_{ele}$  and introduce a mark-up as follows:

$$P_{ele,t} = P_{elemc,t} \cdot (1 + \theta_t) \quad (9)$$

Here  $P_{elemc}$  is the price of energy in a perfectly competitive and equals the marginal cost of producing and supplying electricity, and  $\theta$  is a mark-up. The difference between the two prices gives us the marginal profit rate of the firm.

$$mp_t = P_{ele,t} - P_{elemc,t} \quad (10)$$

If we multiply the marginal profit rate by the total revenue from selling electricity to firms and households ( $Q_{ele}$ ) we have the total profit which is set exogenously and equals the expenditure necessary to reinforce the network (NTW).

$$\overline{NTW}_t = mp_t \left( \sum_h ELE_{h,t} + \sum_w VVe_{\delta,t} \right) \quad (11)$$

NTW is exogenously determined and equals the expenditure necessary to upgrade the electricity network. When NTW is different from zero, the mark-up  $\theta$  will increase by how much is necessary to get the marginal profit that is necessary to raise sufficient funding to pay for the network improvement. To simulate the increase in electricity price we substitute the price of electricity defined in equation (9) in (6) and (8) by setting  $\sum NTW_t$  equal to £2.7billion. However, we assume that while the expenditure takes place in 3 or 12 years, the repayment is spread across 45 years. In year 46, the price mark-up reduces to zero and the economy gradually approaches the long-run equilibrium.

#### 4. Simulation results

##### 4.1. Summary of scenarios simulated

As noted above, we simulate in two stages. Scenario 1 focuses only on the impacts of the spending on electricity network upgrades that is required to support 20% EV penetration across the UK private transportation fleet. That is, without the associated uptake of EVs actually taking place. We base the level of spending simulated on mixed charging scenario, which assumes that 60% of EV charging is decentralised so there is the need for more extensive distribution network reinforcement, while 40% of charging is centralised and therefore the need for distribution network upgrade is limited. The scenario is informed by National Grid's (2018) 'Future Energy Scenarios', with the £2.7billion investment required to support 20% EV roll-out by 2030 determined via an energy system (TIMES) model simulation reported in Calvillo and Turner (2019).

As discussed in Section 3, the timeframe over which the spending on network upgrade takes place will affect the anticipated economy-wide impacts. Thus, we set out two sub-scenarios, Scenario 1a and Scenario 1b. Scenario 1a assumes the spending takes place over the 12-year period between 2021 and 2032. Scenario 1b assumes that the entire spend and upgrade programme takes place within the 3-year period 2027–2029. In both cases, the total £2.7billion cost, £900million (£0.9billion) of which is spent domestically (in the UK Construction sector), is recovered via electricity bills across a 45-year period from the first year of the investment (coincides with the life-span of the assets developed). See Table 1 for a summary of the breakdown and recovery of the investment spending.

Scenario 2 – where Scenarios 2a and 2b incorporate the alternative investment timeframes in Scenario 1 – then introduces consideration of how the roll-out of EVs affects the anticipated impacts. Here, we assume that a gradually increasing percentage of EVs is used to meet the private transportation needs, replacing the conventional internal combustion engine vehicles fuelled with petrol or diesel. The EV penetration is assumed to start at 2% in 2021 and expand by 2% each year until it reaches 20% in 2030. We also incorporate increasing efficiency in the EV fleet. This reflects conditions in the Calvillo and Turner (2019) analysis from which we inform our CGE simulations. By increasing efficiency we mean that by 2030 EVs will be able to cover a 20% longer distance per unit of energy compared to what they can achieve now. We introduce this in step changes, where the efficiency of EVs improve, compared to present levels, by 11% in 2021, 16% by 2025 and 20% by 2030.

**Table 1**  
Breakdown of investment spending and repayment.

a	b	c	d	E
	(a/45 years)	(0.33*a)	(c/12 years)	(c/3 years)
Total investment	Repayment (per year)	Total spending in the UK	UK spend (per year)	UK spend (per year)
£2,700m	£60m	£900m	£75m	£300m

##### 4.2. Scenario 1: impact of £2.7billion spending on electricity network upgrade to support EVs roll-out on key macroeconomic variables, with £0.9billion spending in the UK construction sector

Table 2 summarises key macroeconomic impacts for Scenario 1. The first four numerical columns reporting the case (Scenario 1a) where the network upgrade spending is spread across a 12-year period (2021–2032). We focus on 2021, the first year (short-run) impacts; 2030, the year that the full 20% penetration is achieved; and 2040, ten years on. 2027 is introduced for purposes of comparison with the latter three columns, which report results for the case (Scenario 1b) where the network upgrade spending is spread across a 3-year period (2027–2029). All results in Table 2 are percentage changes relative to the base year (SAM 2010) values.

The results show that the 'demand shock' of the £0.9billion spending in the UK Construction sector to enable the network upgrade, accompanied by the need to repay the £2.7billion (albeit over 45 years) causes some contraction in the economy from the outset. This is due to both the binding constraint on the labour supply (with only the pool of unemployed labour providing excess capacity), the short-term constraint on capital, and the fact that forward-looking producers anticipate that the demand boost is time limited. The nominal wage is assumed fixed. This limits the negative impacts of the labour supply constraint. On the other hand, the user cost of capital is driven up as demand for the output of the Construction sector, and its upstream supply chain rise from the outset. This puts upward pressure on prices across the economy, as reflected in the CPI. Export demand contracts and there is a net decrease in output in all sectors except the Construction sector.

The biggest negative shock in Table 2 is reported for 2030 when the spending is condensed in a 3-year time frame ending in that year (Scenario 1b). Here, there is a contraction of 0.73% in the Electricity sector and a further 0.15% in all other sectors but Construction. This is offset only very slightly in 2030 as resources begin to shift away from that sector in anticipation of the end of the spending programme. By 2040 the contraction eases, and more or less equalises over the two cases reported. Nonetheless (while it is not reported in Table 2), the cumulative loss to UK GDP within the 2021–2040 timeframe is notably larger (£1.33billion) when the spending is condensed in a 3-year period under Scenario 1b relative to that when it is spread over 12 years (£0.87billion).

A key policy concern at this stage is the impact on UK household incomes, and low-income consumers in particular. The results in Table 2 show that household losses track or may exceed proportionate GDP losses. This is because, households bear a direct negative impact from the need to repay the network upgrade costs through their energy bills. This is reflected by the increase in the price of electricity being notably larger than the increase in the marginal cost of electricity (which itself is impacted by the pressure that the expansion puts on the user cost of capital). But Fig. 3 shows that the losses experienced by the lowest income quintile are relatively small, with a limited gain in 2027 under the more condensed 3-year spending scenario (where the construction sector and its supply chain receive the biggest boost, which includes employment impacts).

Generally, we find that UK households with higher incomes tend to lose more, both because of the greater absolute impact on what are higher energy bills overall, and the fact that they are more exposed to changing economic conditions through higher employment and capital ownership.

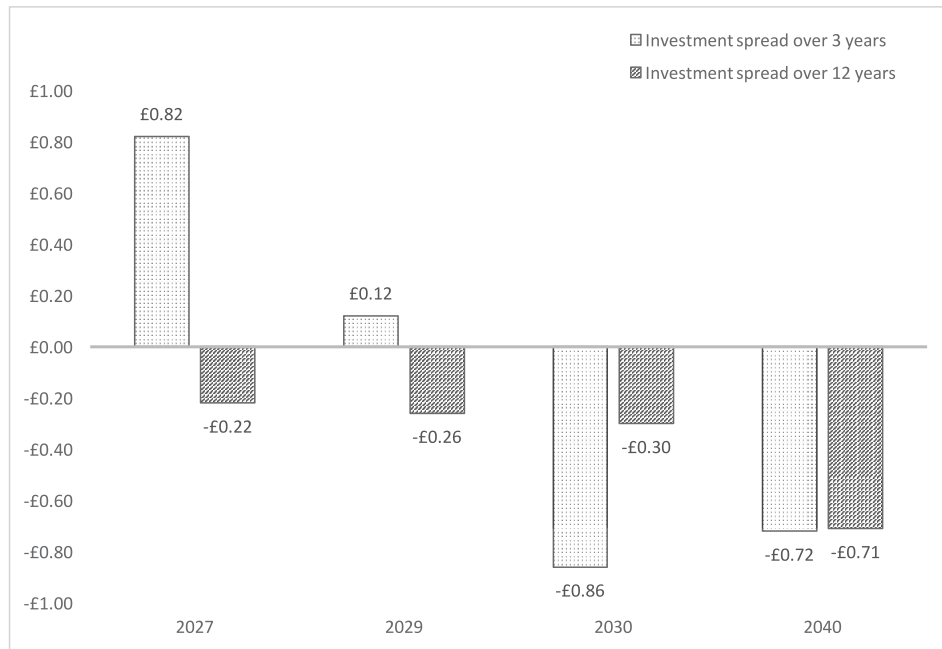
##### 4.3. Scenario 2: combined impact of £2.7billion spending on electricity network upgrade and 20% EV penetration by 2030

For the second stage of our analysis, we introduce the additional impacts of the 20% EV roll-out being achieved by 2030. The combined impacts on key macroeconomic variables are shown in Table 3, the format of which corresponds to that of Table 2.

**Table 2**

Percentage change in key macroeconomic variables from a £2.7billion spending programme to upgrade the UK electricity network.

	Scenario 1a (12-year investment)				Scenario 1b (3-year investment)		
	2021	2027	2030	2040	2027	2030	2040
GDP	0.000	−0.001	−0.002	−0.006	0.004	−0.014	−0.007
CPI	0.003	0.006	0.006	0.004	0.007	0.013	0.005
User cost of capital	0.009	0.004	0.004	0.002	0.035	0.006	0.002
Unemployment Rate	−0.013	−0.010	0.007	0.090	−0.146	0.140	0.094
Employment	0.001	0.001	0.000	−0.006	0.009	−0.009	−0.006
Import	0.002	0.003	0.001	−0.004	0.016	0.003	−0.004
Export	−0.003	−0.008	−0.008	−0.006	−0.010	−0.022	−0.007
Electricity output	−0.043	−0.062	−0.063	−0.067	−0.041	−0.073	−0.067
Construction output	0.029	0.043	0.035	−0.009	0.111	0.002	−0.009
All other output	−0.002	−0.004	−0.005	−0.007	−0.002	−0.015	−0.007
Price of Electricity	0.084	0.104	0.105	0.104	0.088	0.107	0.104
Marginal cost of electricity	0.012	0.032	0.032	0.031	0.015	0.035	0.032
Real household spending	−0.002	−0.003	−0.004	−0.007	0.003	−0.013	−0.007

**Fig. 3.** Net change in per household real income of £2.7bn spending on electricity network upgrades.**Table 3**

Percentage change in key macroeconomic variables from £2.7billion spending to upgrade the UK electricity network combined with the enabled 20% EV roll-out.

	Scenario 2 (12 year investment)				Scenario 2 (3 year investment)		
	2021	2027	2030	2040	2027	2030	2040
GDP	0.007	0.080	0.101	0.102	0.085	0.088	0.101
CPI	0.012	0.013	0.013	0.008	0.014	0.020	0.008
User cost of capital	0.027	0.011	0.010	0.005	0.042	0.012	0.005
Unemployment Rate	−0.202	−1.521	−1.967	−1.934	−1.657	−1.834	−1.930
Employment	0.013	0.097	0.126	0.123	0.106	0.117	0.123
Import	0.032	0.016	−0.021	−0.030	0.029	−0.020	−0.029
Export	−0.022	−0.020	−0.009	−0.008	−0.022	−0.023	−0.009
Electricity output	−0.092	1.955	2.992	3.055	1.976	2.983	3.054
Construction output	0.083	0.165	0.151	0.103	0.233	0.118	0.103
All other output	0.001	0.065	0.086	0.087	0.067	0.076	0.086
Price of Electricity	0.083	0.121	0.138	0.111	0.105	0.141	0.112
Marginal cost of electricity	0.012	0.032	0.032	0.031	0.015	0.035	0.032
Real household spending	0.003	0.048	0.062	0.061	0.054	0.053	0.061
Household consumption of electricity	−0.189	4.546	7.065	7.079	4.560	7.059	7.079
Household consumption of refined fuels	0.004	−10.582	−16.785	−16.810	−10.573	−16.792	−16.810
All other household consumption	0.012	0.025	0.026	0.023	0.033	0.018	0.023

The key result here is that introducing the EV roll-out enabled by the network upgrade generally results in a sustained net positive impact on GDP, total employment, and household spending. On the other hand, introducing the additional boost to domestic demand does put more pressure on the constrained economy in the early periods, so that the increase in the CPI is generally around double in Scenarios 2a and 2b relative to what is reported for Scenarios 1a and 1b, and the decrease in export demand is exacerbated. On the other hand, it is the sustained net boost in domestic demand through the roll-out of EVs that permits a sustained boost to GDP, employment and real household spending (where, the later includes a shifts from petrol and diesel to electric fuelling).

Fig. 4 plots the trend and net impacts on key macroeconomic variables for the case where the network upgrade spending is spread over 12 years (Scenario 2a). Note that the increase in real household spending always trails GDP expansion, given the need to continue to repay the network upgrade cost via higher energy bills. This is exacerbated by the fact that the uptake of EV increases demand for electricity, putting further upward pressure on both the price of electricity and the CPI.

The change in the composition of economic activity is crucial, particularly in terms of the nature of the net employment gains delivered. Fig. 5 reflects the finding the greater reliance on domestic (UK) supply chains in supporting fuelling of electric rather than petrol and diesel cars is crucial in delivering important policy-relevant gains. In all periods, the greatest employment boosts are observed in the electricity sector itself and in public and private service sectors. The gross employment gains are maximised in 2040 at 3071 jobs and set against a gross sustained loss of 115 jobs in the same period, with the latter confined to the manufacture and fuelling of petrol/diesel vehicles and offset in other sectors.

#### 4.4. Sensitivity analysis

As in any modelling analysis, we have made assumptions in our model that could potentially impact the magnitude and nature of some of the key policy-relevant variables and insights reported. Here, given that we observe a contraction in the economy when the ‘demand shock’ of the spending on network upgrades is introduced, we focus on two of the key assumptions governing the adjustment in capacity.

First, as explained in Section 4, our assumption of forward looking producers (who have perfect foresight – see equation (1) in Section 4) means that resources begin to be reallocated before the spending programme actually ends in all our scenarios. In Table 4, we report results where this assumption is relaxed so that producers behave in a myopic manner, not anticipating the end of the programme. This means they only reallocate resources after spending ends.

Second, in the scenarios above, we assume that nominal wages are fixed. This limits the impact of constrained capacity by not allowing the nominal price of labour to rise as demand grows. On the other hand, it will also constrain any expansion as the incentive for unemployed labour to join the workforce is limited. In Table 4 we report results where wages are determined using the bargained real wage function in equation (3).

Taking the central case example of Scenario 2a, Table 4 shows that relaxing the central case assumptions in these two regards does have some impact on the quantitative results reported. As would be expected, the myopic producers results on the right of the table reflect a slightly larger expansion in the economy in all periods. Relaxing the assumption of fixed nominal wage rates has a less uniform impact. The results in the bottom half of Table 4 reflect a greater underlying contraction in response to the network upgrade spending and more limited expansion in response to the EV roll-out as upward pressure on wages exacerbates the impact of the constraints on capacity. But over time (here by 2040), the wage flexibility enables a greater expansion through industries being

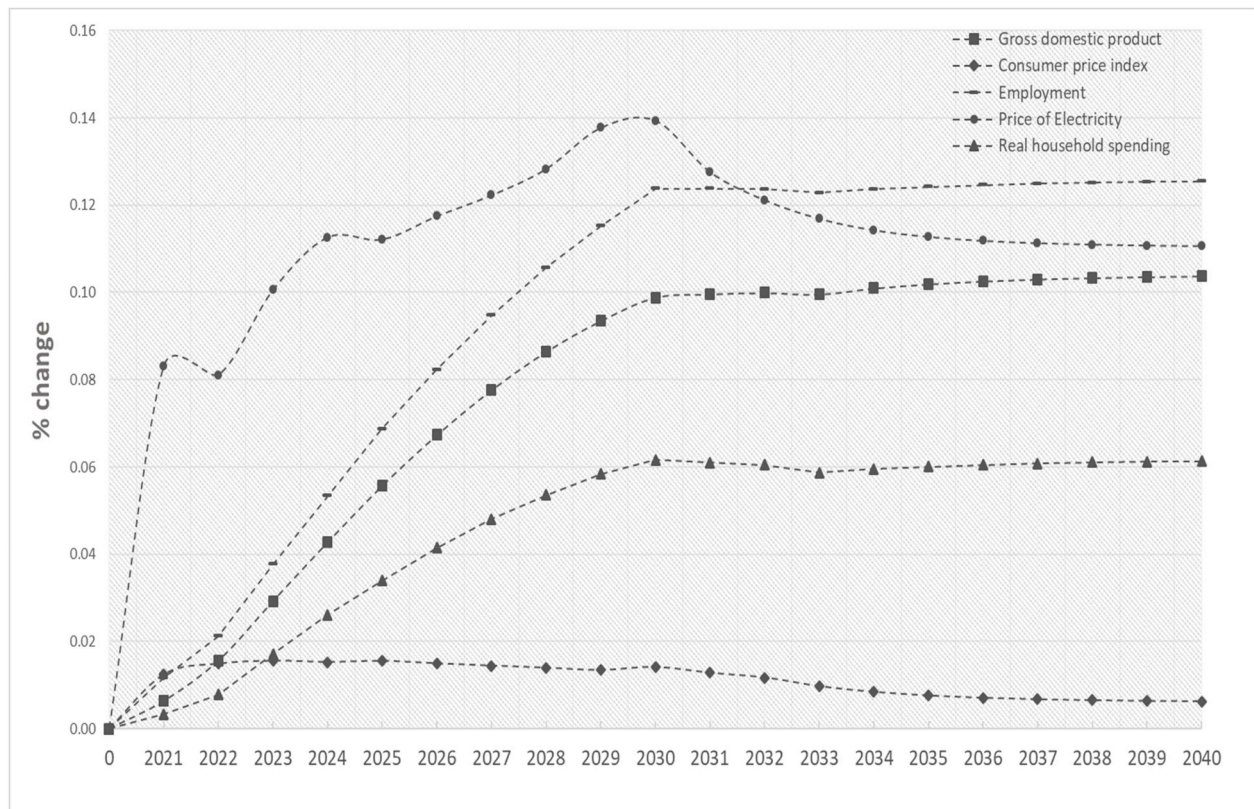


Fig. 4. Net impacts on wider economy of 20% EV penetration by 2030 and required sending on network upgrades (Scenario 2a).



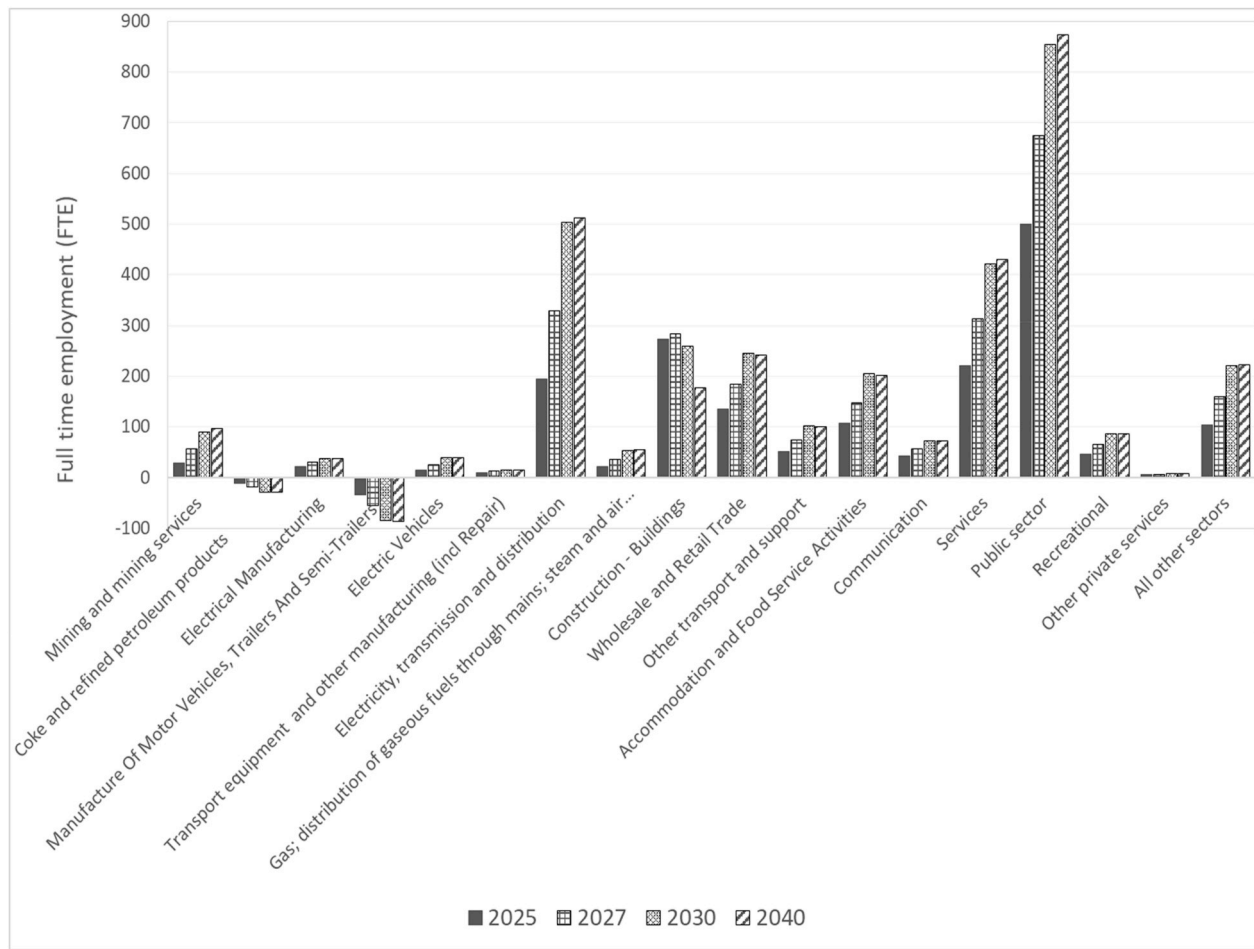


Fig. 5. Net impacts on sectoral employment of 20% EV penetration by 2030 and required spending on network upgrades (Scenario 2a).

Table 4

Sensitivity analysis: Scenario 2a (spending on network upgrade combined with EV roll-out).

		Forward looking producers (central case)			Myopic producers		
	Macroeconomic variables	2027	2030	2040	2027	2030	2040
Fixed nominal wage (central case)	GDP	0.080	0.101	0.102	0.081	0.104	0.103
	CPI	0.013	0.013	0.008	0.012	0.012	0.007
	Unemployment Rate	-1.521	-1.967	-1.934	-1.539	-2.005	-1.943
	Employment	0.097	0.126	0.123	0.098	0.128	0.124
	Household real income	0.048	0.062	0.061	0.049	0.064	0.062
Bargained real wage	GDP	0.078	0.099	0.104	0.079	0.101	0.105
	CPI	0.014	0.014	0.006	0.014	0.014	0.005
	Unemployment Rate	-1.484	-1.939	-1.965	-1.493	-1.957	-1.972
	Employment	0.095	0.124	0.125	0.095	0.125	0.126
	Household real income	0.048	0.062	0.061	0.049	0.063	0.062

better able to draw on the pool of unemployed labour.

## 5. Conclusions and policy implications

Generally, the analyses presented here serve to demonstrate the need to shift focus from the technology and investment concerns associated with large new low carbon initiatives to focus on how the new activity enabled may unlock, sustain and increase value in different parts of the economy. In the case of enabling the first stage of EV roll-out in the UK presented here, our results reported raise questions as to whether we may have been missing a key source of value in terms of how we have fuelled our vehicles in the past. We have shown that a shift in household spending to fuel vehicles from more import intensive petrol and diesel

towards the outputs of the more domestically integrated electricity industry, will generate multiplier effects that allow the economy to expand. On the other hand, our results show that the presence of supply constraints, particularly where the production side of the economy anticipates that large-scale spending programmes are time limited, is likely to mean that gains in domestic activity are achieved at the cost of higher price levels and a drop in export demand.

There are a number of ways in which the research presented here should be extended to yield important insights for policymakers. For example, if the network upgrades enable efficiency increases in energy supply, some of the negative prices effects observed in our results may be less extensive. But, at this stage, the initial results and analysis presented here allow us to draw a core policy-relevant conclusion. This is that UK

policy makers and industry need to consider how to capitalise on the type of wider economic returns to low carbon development, how the timing of spending programmes should be planned to maximise these, and how prevailing conditions in the wider economy may impact outcomes. Our results clearly show that, even in the presence of capacity constraints, the ongoing EV roll-out and other low carbon initiatives are likely to deliver greater gains where domestic capacity can be fully and effectively utilised, and that the process may not overly disadvantage low income households.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.enpol.2019.111117>.

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